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ABSTRACT

A low cost communications network has been designed for use in the PLATO IV computer-assisted instruction system. Over 1,000 remote computer graphic terminals each requiring a 1200 bps channel are to be connected to one centrally located computer. Digital data are distributed to these terminals using standard commercial cable television (CATV) equipment and a PLATO IV network interface unit. The data are transmitted in a synchronous time division multiplexed mode which is compatible with standard television signals. The receiver is contained in the PLATO IV site controller which also houses the circuits for multiplexing information from terminals onto a single voice grade phone line for transmission back to the computer center. The communications cost of this technique is approximately one-tenth of the costs of using a single voice grade telephone line per terminal. (CH)

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DIGITAL DATA TRANSMISSION VIA CATV

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DIGITAL DATA TRANSMISSION VIA CATV

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ABSTRACT: This report will describe a low cost communications network designed for use in the PLATO IV computer-assisted instruction (CAI) system. In this system over 1000 remote computer graphic terminals, each requiring a 1200 bps channel, are to be connected to one centrally located computer. A technique will be described for distributing digital data to these terminals via standard commercial cable television (CATV) equipment. The data is transmitted in a synchronous time division multiplexed mode which is compatible with standard television signals. It will be shown that the communications cost of this technique is approximately 1/10 of the cost of using a single voice grade telephone line per terminal.

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DIGITAL DATA TRANSMISSION VIA CATV

1.0 Introduction

This report describes a digital data transmitter and receiver designed for use in standard CATV (community-antenna-television) systems. This equipment has been developed for use in the communication network of the PLATO IV computer-assisted instruction (CAI) system.

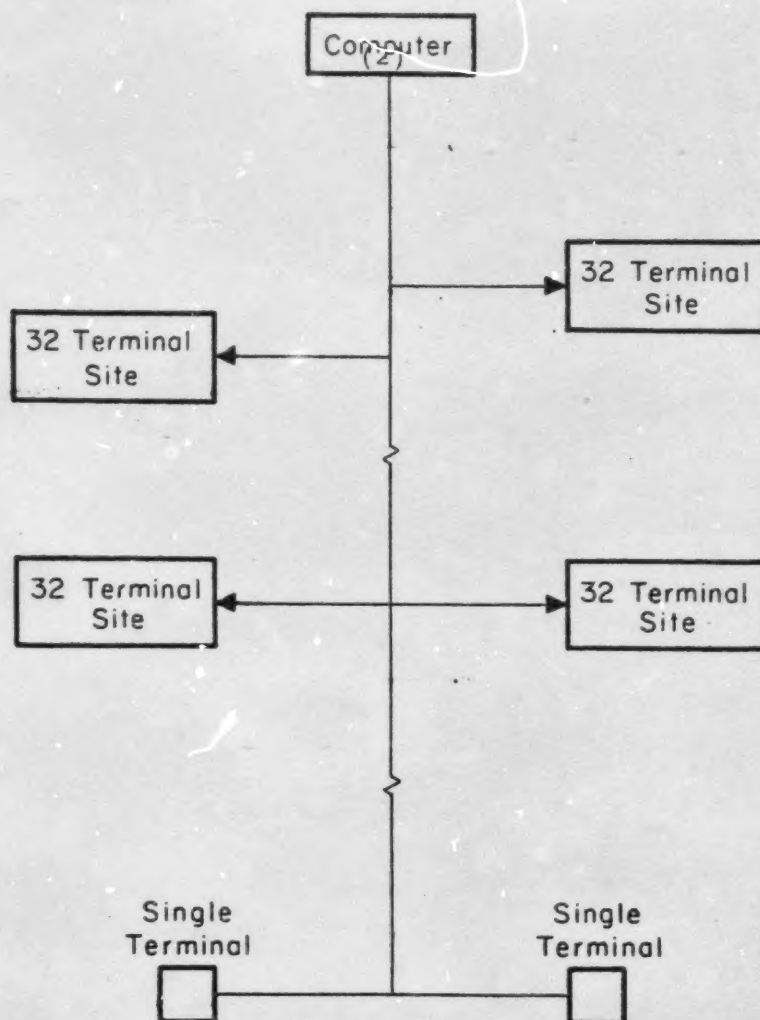
2.0 PLATO IV

Much has been written elsewhere (1,2) describing PLATO IV and therefore only a brief general description will be given here. In a typical PLATO IV system, approximately 1000 remotely located computer terminals, each requiring an input bandwidth of approximately 1200 bps, must be connected to one centrally located computer. Most of these terminals will be located in classroom installations of up to 32 terminals each. Some of these classroom installations will be located within a few miles of the computer site, while others will be a few hundred miles distant. In addition to these classroom installations, a limited number of individual remotely located terminals must also be serviced. Thus, a typical PLATO IV system would be configured as shown in Figure 1.

The problem is how to economically distribute digital data through such a network.

3.0 Communication Costs

The Bell system offers a wide variety of transmission channels and equipment to meet data communication requirements. Single voice grade channels are available which can easily handle data rates of 1200bps. Wideband service, offering the equivalent of up to 240 or more voice grade channels, is available in a single package.



GR-637

Figure 1. Typical PLATO IV System

The inter-state tariffs for leasing these voice grade lines range from \$4.50/mile/month for a single channel (type 3002) to as low as 60¢/mile/month channel for Series 5000 (240channels) service. (All tariffs quoted should be considered approximate. They may vary with geographical location an individual service required).

Using even the lowest cost figure above, the communication costs for a system of the size of PLATO IV become prohibitive, especially over long distances. An attractive alternative does exist, however, through the use of educational television (ETV) channels. The present tariffs for an ETV channel range from \$30 to approximately \$55/mile/month or less depending upon the number of channels leased and distances involved. At these rates, it is apparent that if as few as 50 to 100 users share an ETV channel, the communication costs are competitive with the wide-band service quoted above.

This report will show how a single ETV channel can be used to supply 1200bps service to more than 1000 users, resulting in per user charge for the channel of from 3¢ to 5.5¢/mile/month.

Such a channel will be used to distribute digital data to classrooms in the same manner that commercial TV programs are distributed, via CATV, to private homes.

4.0 Composite Television Signal

Before proceeding with a description of the equipment a brief discussion of the composite television (TV) signal is in order.

The composite black and white TV signal is assembled from three signals. These are:

1. A composite synchronizing signal which is made up of two parts, horizontal sync signal and a vertical sync signal.

2. A composite blanking signal which is also composed of two parts, a horizontal blanking signal and a vertical blanking signal.
3. A video signal which contains the picture information. This signal is normally used by television receivers to intensity modulate the horizontal scanning lines. In the system described here the video signal contains the digital data.

Details of the FCC standard synchronization signal are shown in Figure 2.0. All times are given relative to H, the time interval between horizontal sync pulses ($H = \frac{1}{15750}$ sec = 63.5 sec.). The vertical blanking time shown is the minimum allowed by FCC standards.

The equalization pulses and the serrating pulses in the vertical sync interval are of little value in the system described in this report and therefore the reasons for their existence will not be discussed here. (More details may be found in references 3 and 4.) They must, however, still be generated by the transmitter in order that standard commercial equipment may be used for transmission and reception.

In the United States television system, there are 30 frames transmitted per second, each frame containing 525 lines. To reduce flicker in the picture, each frame is transmitted as two fields of $262\frac{1}{2}$ lines each at a rate of 60 fields per seconds, with the lines of one field interlaced between the lines of the other. The vertical blanking interval requires up to 21 lines leaving a maximum of $241\frac{1}{2}$ lines to be used for video.

5.0 PLATO Video (Data) Signal

Because digital information is binary in nature, only two voltage level are required to represent the information. In the system described here the white level is chosen as logical "one" and the black level as logical "zero". This choice of levels

(5)

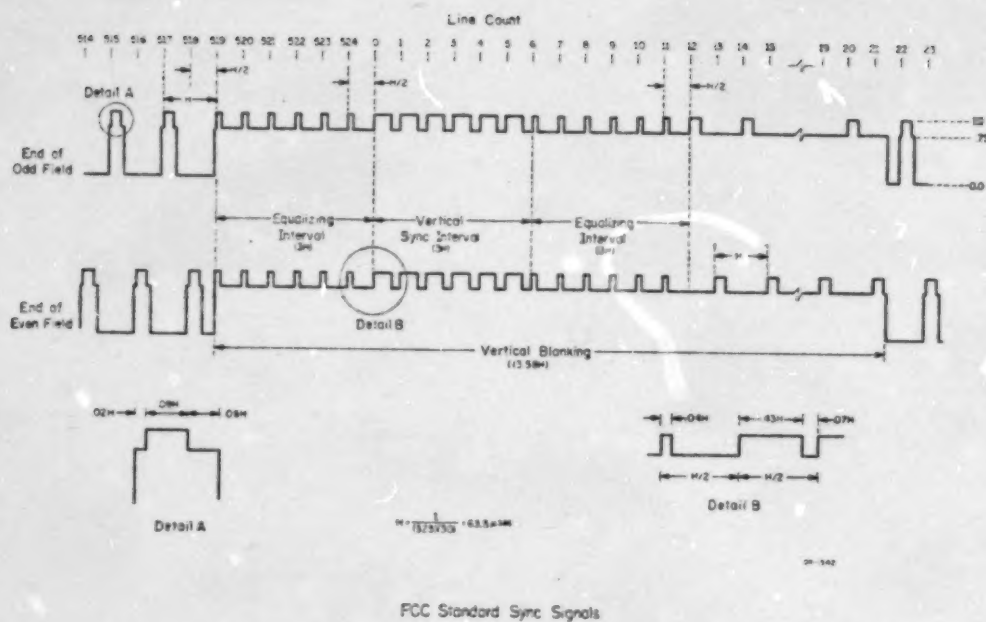


Figure 2. FCC Synchronizing Signal

reduces the average power consumption in any line amplifiers present in the Bell system, because these amplifiers consume more power at the white level and the PLATO signal contains far more "zeros" than "ones".

Each horizontal scanning line in the television field which carries data is divided into 100 time bins of .01H seconds each. This choice of bin width fits within the FCC requirements for horizontal bandwidth and also relaxes the specification on the local oscillator in the receiver to be described later. The first 16 bins of each line are used for horizontal synchronization and blanking purposes while each of the remaining 84 bins contains a bit of digital information. An example of a line carrying digital data is shown in Figure 3.0.

The data rate for the system is given by the following equation:

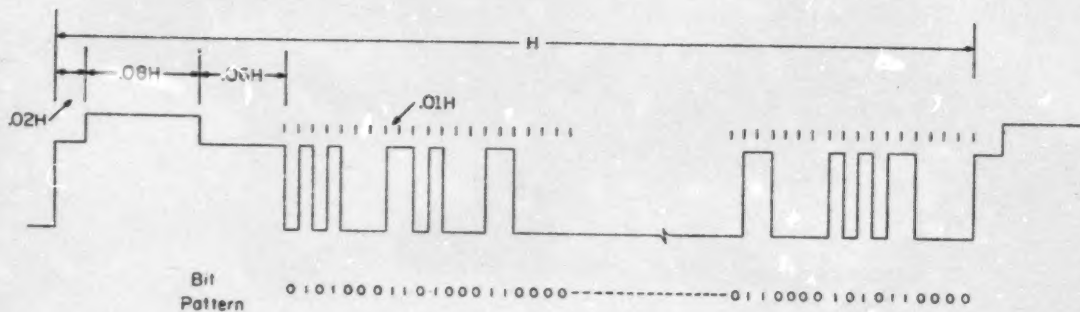
$$\text{Data rate} = 60 N_L N_B \text{ bits per second}$$

where N_L = number of lines per field used to carry data
 N_B = number of bits per line

In the system described here, 240 lines per field, each containing 84 bits are used giving a data rate of 1.2096×10^6 bits per second.

Each PLATO IV terminal⁵ operates on a word size of 20 bits in length and requires up to 60 words per second, or a data rate of 1200 bits per second. One TV frame can, therefore, supply data to $\frac{1.2096 \times 10^6}{1200} = 1008$ terminals. The format of the data within a TV frame is shown in Figure 4.0. Each terminal receives bit i of a data word followed by bit $i + 1$ etc. This format thus requires $\frac{1008}{84} = 12$ TV lines to transmit one bit of

(7)



DR-1530

Figure 3. Horizontal Scanning Line Containing Digital Data

data to each terminal.

Figure 5.0 is an actual photo taken from the standard TV screen illustrating the format of the data for two terminals. On the left, terminal 16 is receiving the word 0011010111011011001 (reading from top to bottom), while on the right, terminal 42 is receiving the word 01111110110111100110.

6.0 Transmitter

The transmitter generates the standard television synchronization and blanking signals and combines these signals with the digital data into a composite signal compatible with FCC standards. The composite signal is then delivered to the common carrier supplying the TV channel for RF modulation and transmission over standard cable television (CATV) equipment.

A block diagram of the transmitter is shown in Figure 6.0.

The Clock Control circuit contains a 1.575 MHz crystal controlled oscillator (clock) which drives a divide by 50 counter. The outputs of the counter and the clock signals are sent to the Pulser circuit where they are used to generate the four pulses shown in Figure 7.0.

The V pulse is used to drive a Divide by 525 counter, the outputs of which are interpreted as the horizontal line count within a frame. (The line count is shown at the top of Figure 2.0.)

The Signal Composer circuit assembles the composite synchronization and blanking signals using the four pulses supplied by the Pulser circuit as building blocks. The outputs of the Divide by 525 counter are used by the Signal Composer to supervise assembly of the composite signals.

(9)

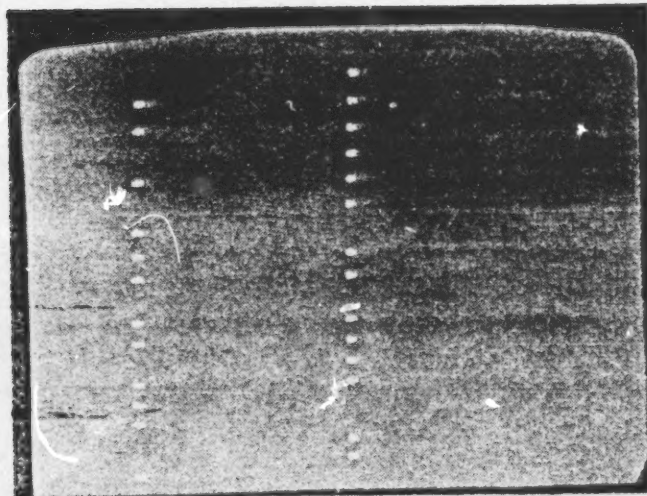
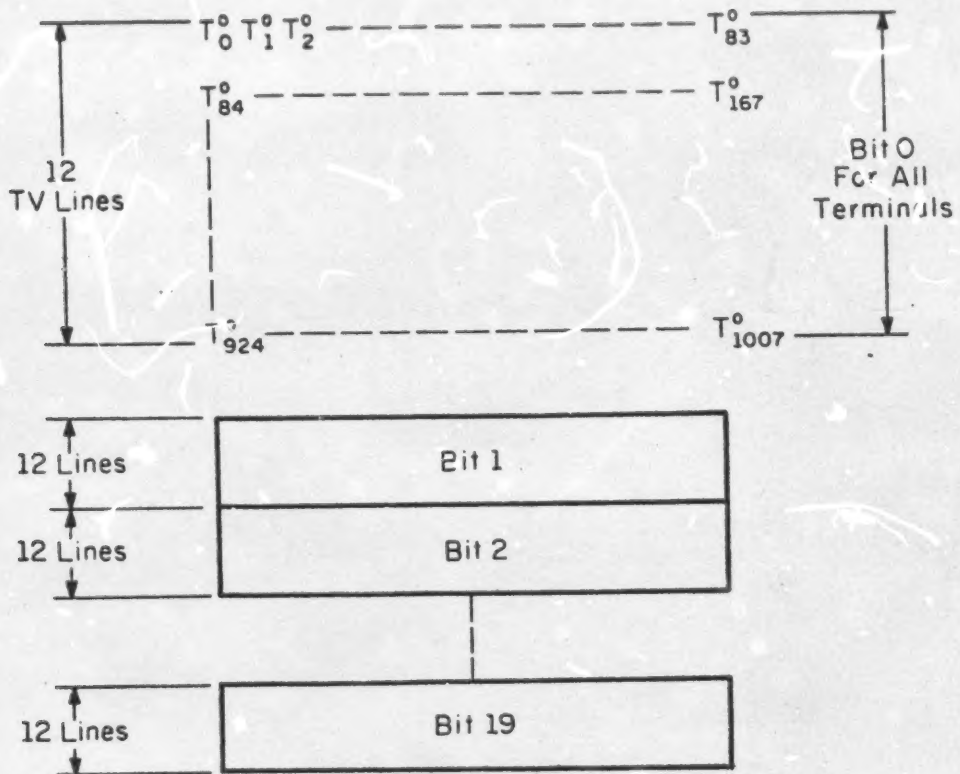
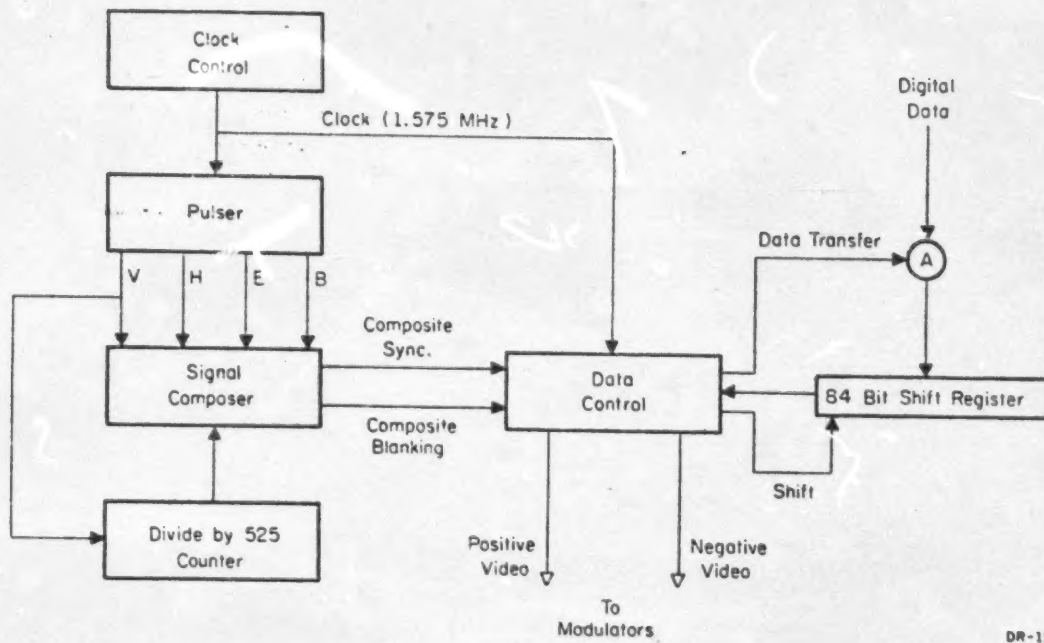


Figure 4. PLATO Data Format
Figure 5. Photo of TV Field

(10)



DR-1529

Figure 6. Transmitter

The composite sync and blanking signals along with the clock signal are sent to the Data Control circuit which performs two functions:

1. The generation of the timing and control signals necessary for the transfer of digital data into the transmitter.
2. The assembly of the data, the sync, and the blanking signals into a composite signal.

The data to be transmitter is assumed to be in the form of 84 bit words. At the start of each line a data word is loaded into the shift registered by the Data Transfer signal. At the conclusion of the horizontal blanking interval the data is shifted into the Data Control circuit by the shift (1.575 MHz) signals. The composite signal is then sent to standard television RF modulators for transmission over standard TV channels.

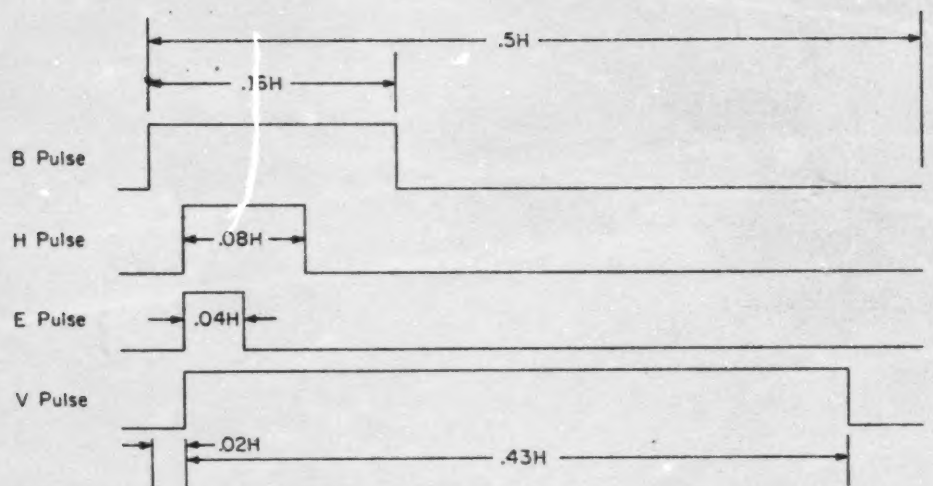
7.0 Receiver

Two basic functions are performed by the data receiver, the recovery of the digital data and the generation of data addresses. This latter function is necessary to facilitate separation of the data when it is transmitted in a time-division-multiplex mode and must be delivered to multiple destinations.

A block diagram of the data receiver is shown in Figure 8. An RF receiver similar to the front end of a standard commercial television receiver is used to recover the composite video signal from the RF carrier. The composite signal is delivered to the TV interface circuit where it is clamped and then separated into sync and video (data) components. The video signal is placed on the data bus while the sync signal is sent to the Sync Detector circuit.

The Sync Detector circuit separates the vertical and horizontal sync signals and supplies these signals to the data addressing circuits.

(12)



DR-1932

Figure 7. Pulser Outputs

(13)

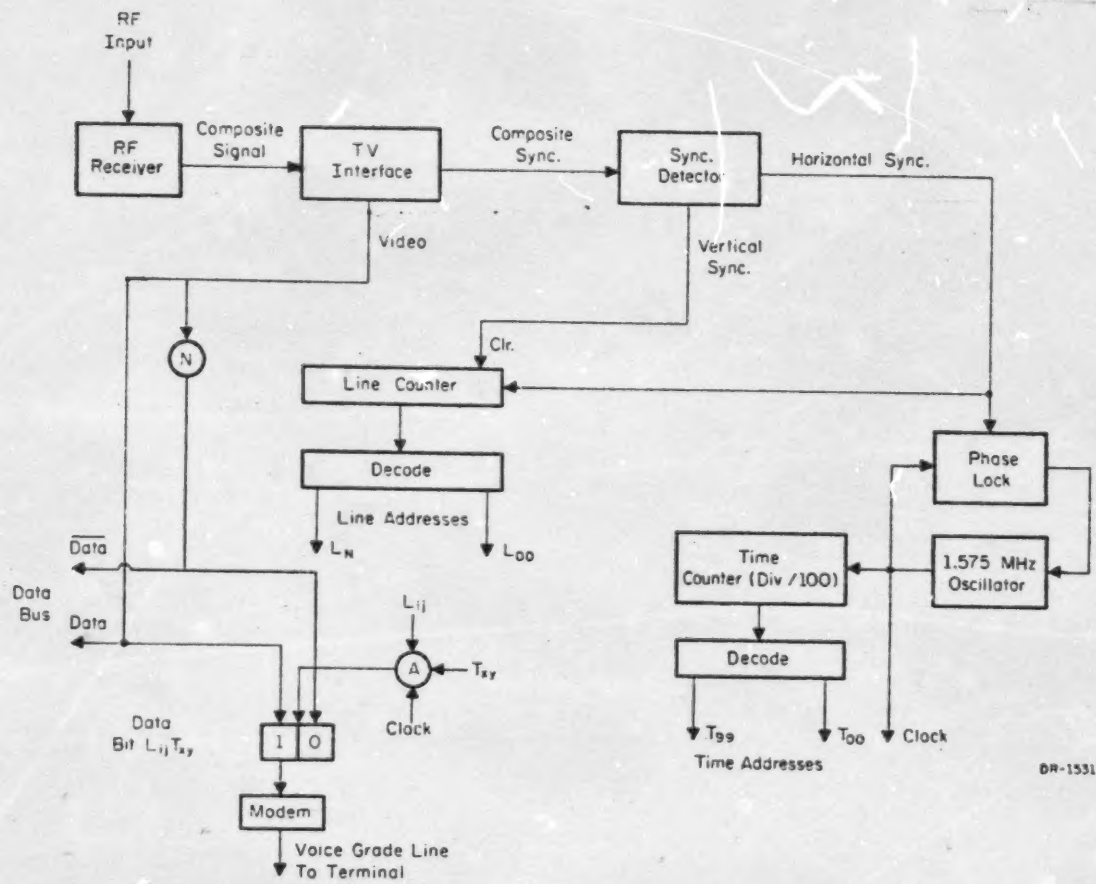


Figure 8. Receiver

Data addresses are specified by:

- a) a line address designating the line on which a data bit occurs and
- b) a time address specifying the time bin along that line which contains the data bit.

The line address is specified by the Line Counter which effectively counts horizontal sync pulses. The time address is obtained from the Time Counter which is driven by a 1.575 MHz oscillator. This oscillator is phase locked to the horizontal sync pulse and provides an accurate source for strobing the data bins along a line.

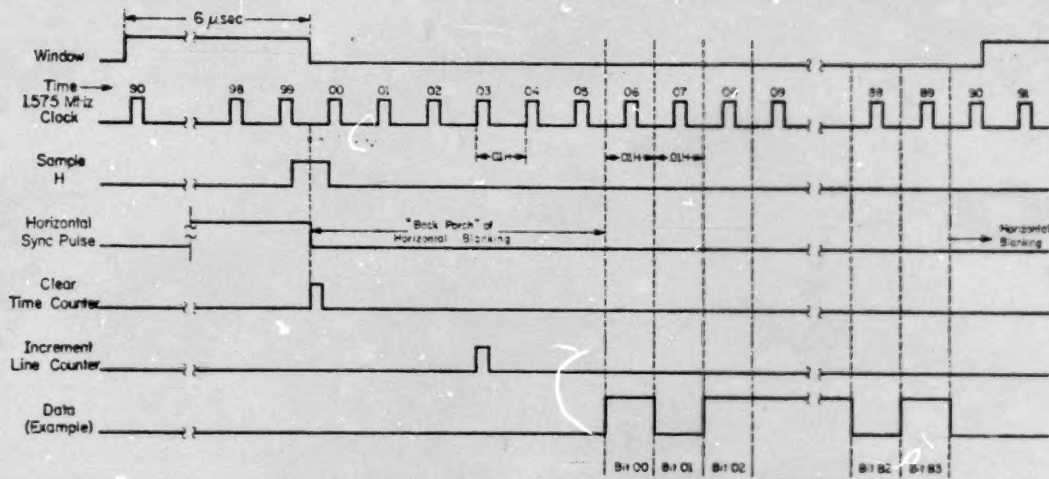
The data, after recovery from the data bus, is delivered to a modem which converts the data into a frequency shift (FSK) signal for transmission to the terminal over voice grade lines.

8.0 Receiver Synchronization

Successful recovery of incoming data depends upon the synchronization of the addressing circuits with the incoming signal. The details of receiver synchronization are shown in Figure 9.0.

The horizontal sync signal is viewed by the addressing circuits through a 6 μ sec window. This window is initiated by the clock time 90 (T_{90}) from the 1.575 MHz clock and terminated by the trailing edge of the incoming horizontal sync pulse. Between clock time 99 and 00 a Sample H pulse is generated by the Time Counter and is used to sample the horizontal sync signal as seen through the window. During this Sample H interval the frequency of 1.575 MHz oscillator is adjusted such that the oscillator remains phase locked to the trailing edge of the horizontal sync pulse. At the conclusion of the horizontal sync pulse a Clear pulse is generated which sets the Time Counter to zero thus placing the counter "in step" with the train of sync pulses.

(15)



Receiver Synchronization

04-1543

Figure 9. Receiver Synchronization

The Line Counter is not actually incremented by the horizontal sync pulse but instead by a pulse at clock time 3 from the Time Counter. Noise which may be present in the horizontal sync signal is thus prevented from entering false counts into the Line Counter. It is apparent, of course, that noise present on the sync signal during the window interval can still cause errors by generating erroneous Clear pulses. The window, however, is open only for 6 usec per line, and the clearing of the Time Counter (generation of the Clear pulse) is permitted only for the first 12 horizontal sync pulses in a field plus the equalizing interval (approximately 3 lines) following the vertical sync signal, or approximately

$$\frac{3}{262.5} + \frac{6}{63.5} + \frac{12}{262.5} \times 100 \approx 2\% \text{ of the time}$$

Except for the vertical sync interval, the phase-locking operation occurs for every line in a field.

9.0 Performance

Field testing of the prototype version of the equipment has been conducted on a 180 mile long loop facility provided by the Illinois Bell Telephone Company. Data has been recorded at various times of the day over a one month period during which approximately 80 hours of data have been accumulated.

The 180 mile loop facility employs three methods of video transmission that are presently being used to transmit video in the AT&T system. Information is transmitted as "base-band" (DC to 8MHz) from the University of Illinois to the Illinois Bell Office in Champaign (approximately 2 miles). From there the video is transmitted via a microwave link to Springfield, Illinois and back to Champaign for distribution over the television facilities of the University of Illinois. The video is carried on Channel 5 (76-82 MHz) on the University cable facilities. Channel 5 was chosen because it is between two channels, 4 and 6, presently in use and thus provides a worst case noise condition.

Data was recorded using an input signal level at the receiver of 0 dbmv. The test data was transmitted in the form of alternating "1's" and "0's". At the receiver each bit received not in agreement with the transmitted bit was recorded as an error. Most of the errors occurred in burst of random length. The results of the test are tabulated in Table 1.

The success of this data transmission technique will depend on the ability to detect and retransmit erroneous data. The data format presently used, see Figure 4.0, permits a 1 bit parity check to catch error bursts that are equal to or less than 12 horizontal lines (1008 bits) in length. From Table 1 it is noted that over 88% of the error bursts satisfy the requirement.

10.0 Summary

The technique described here has been incorporated into the PLATO IV communication hardware. The transmitter is contained in the PLATO IV Network Interface Unit shown in Figure 10. This unit performs all of the functions necessary for interfacing a Control Data Corporation 6400 computer to CATV transmitting equipment. Also housed in this unit are the circuits for handling keyset information returning from all of the terminals in the system. (A more detailed description of the Network Interface Unit may be found in reference 2.)

The receiver is contained in the PLATO IV Site Controller shown in Figure 11. This unit contains, in addition to the receiver, the multiplexing circuits and modems for servicing up to 32 terminals. Also housed in this unit are the circuits for multiplexing the keyset information from these terminals onto a single voice grade phone line for transmission back to the computer center. (See reference 2 for more details concerning this unit). A block diagram illustrating the use of the Site Controller in a typical PLATO IV site configuration is shown in Figure 12.

(18)

Total Run Time	78.35 hours
Total Bits Transmitted	3.41×10^{11}
Total Number of Error Bursts	85
Average Time Between Bursts	.92 hours
Bits Transmitted Between Bursts	4×10^9
Shortest Observed Burst	1 bit
Longest Observed Burst	264,009 bits
Average Burst Length ¹	1998 bits
% of Bursts less than 1008 bits	88.2%
Bits transmitted per bit in error ²	2.08×10^6

- 1) The three longest bursts are excluded from this figure. Including these bursts the average burst length was 10,732 bits.
- 2) The three longest bursts were excluded from this figure. If included this number becomes 3.74×10^5 bits transmitted per bit in error.

Table 1. Test Results

(19)

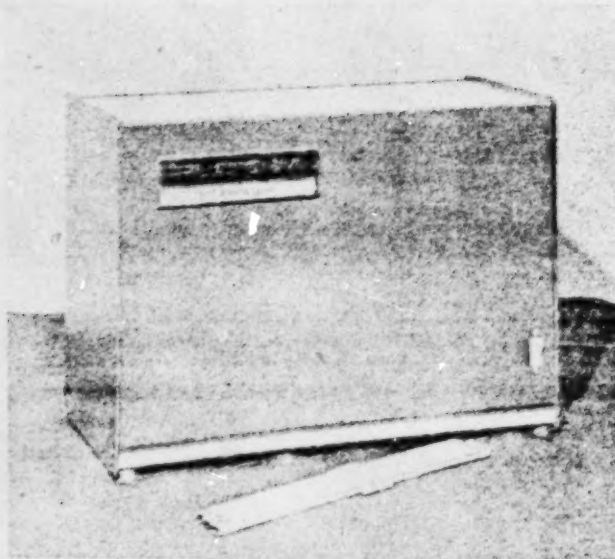
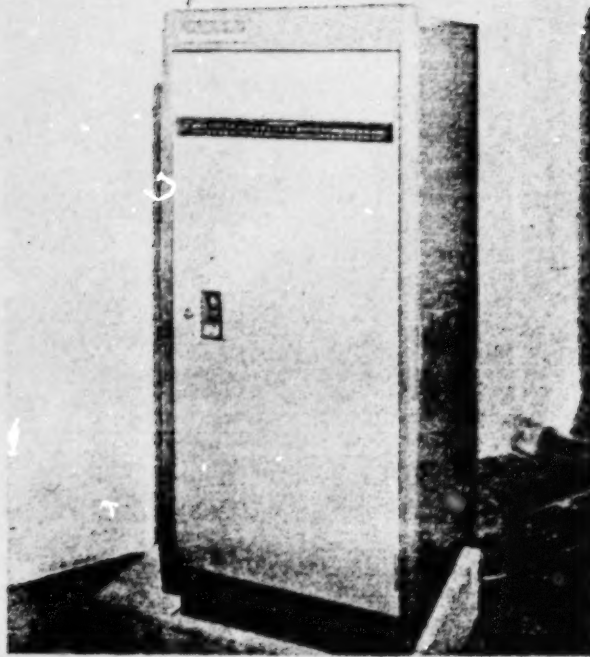
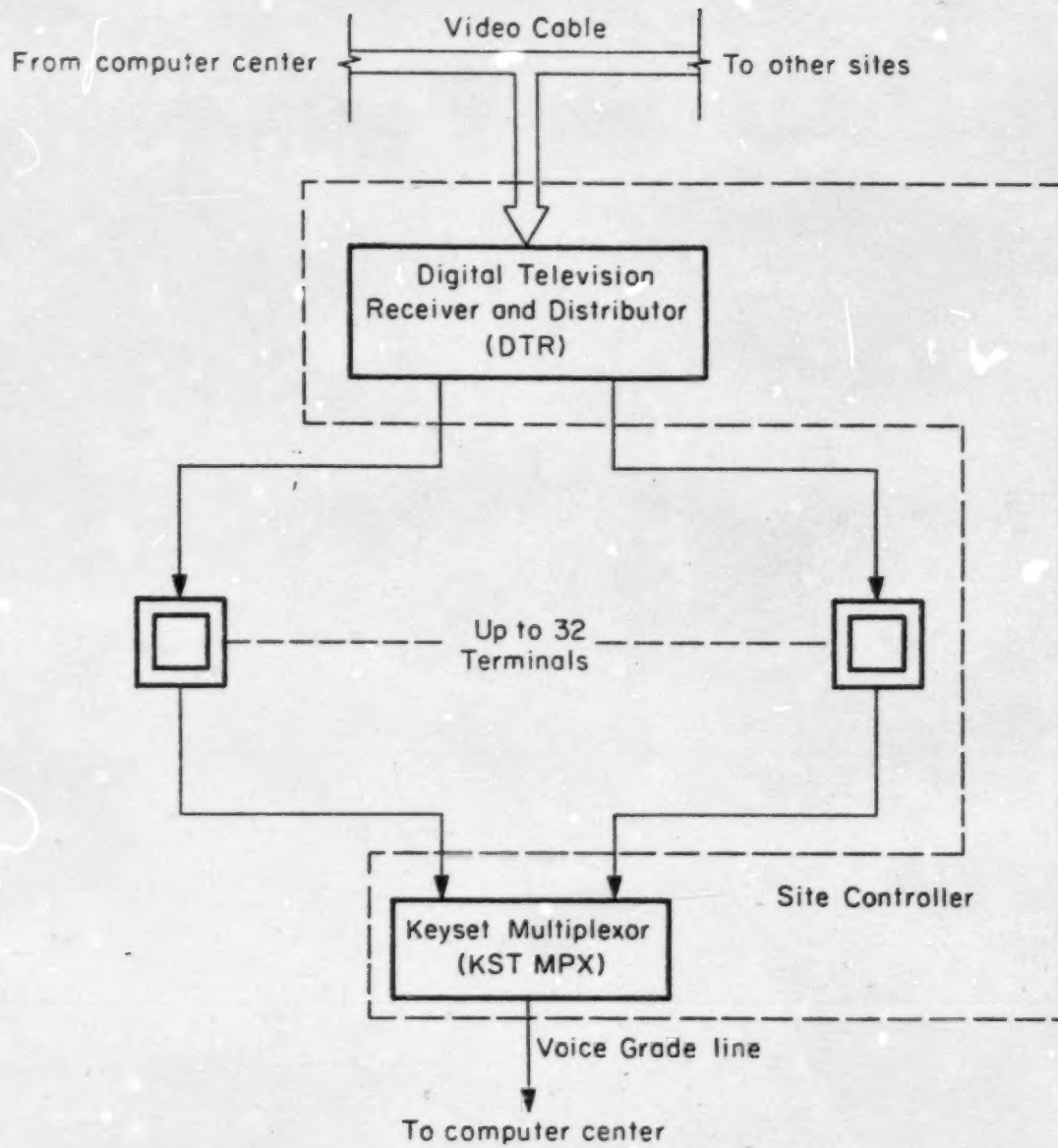


Figure 10. PLATO IV Network Interface Unit
Figure 11. PLATO IV Site Controller

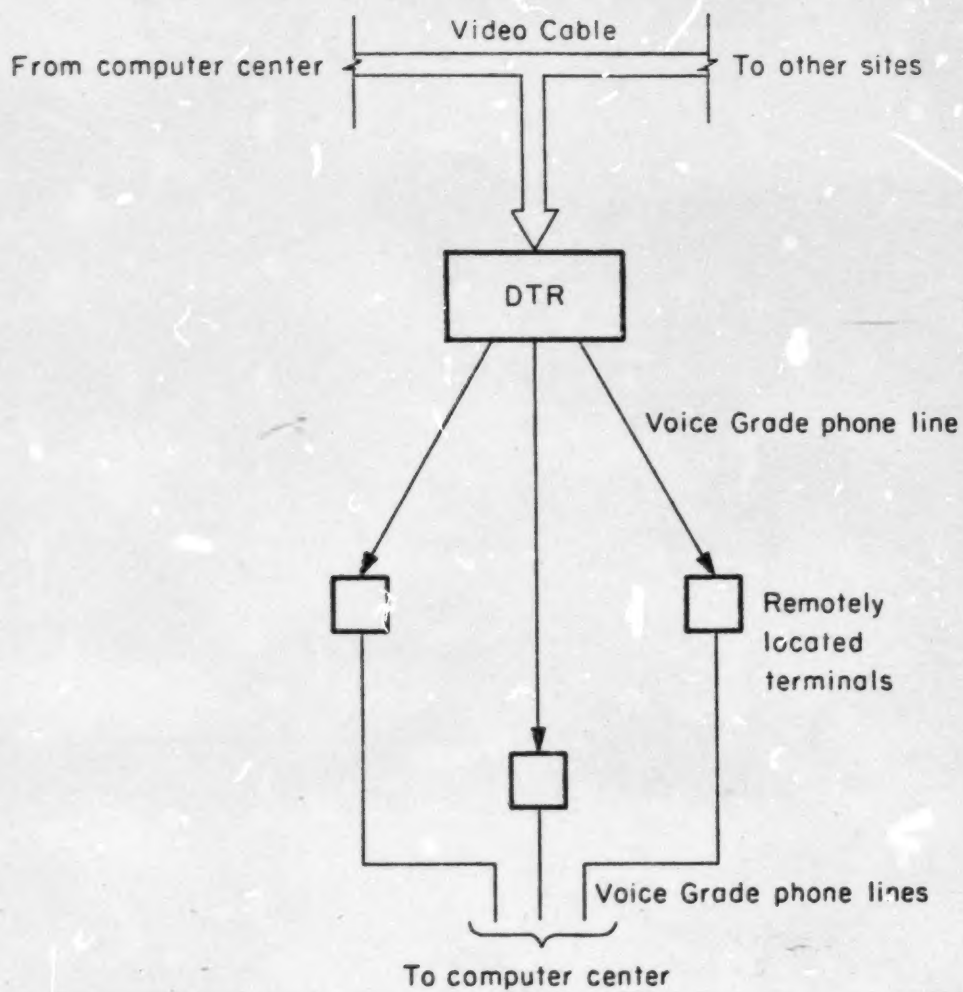
(20)



GR-640

Figure 12. PLATO IV Site Configuration

(21)



GR-639

Figure 13. Single Terminal Service

A receiver unit identical to that used in a Site Controller may also be used to service individual remotely located terminals. For this type of service the receiver is placed at some convenient location along the CATV cable. Voice grade telephone lines are then used to carry the data recovered from the TV carrier to the terminals as shown in Figure 13.

Although the communications technique described here was developed to satisfy the requirements of a CAI system, it need not be restricted to such use. Many other digital data distribution systems could successfully employ this technique.

There are, at present, an estimated 6 million subscribers of CATV service and the number is expected to increase dramatically in the coming years. Millions of homes will then be already wired to receive information from centralized data sources. The communication technique described here could carry such information into those homes over the same path which now carries only commercial TV signals.

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